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MICROGRAVITY FLUID MANAGEMENT REQUIREMENTS OF ADVANCED SOLAR DYNAMIC POWER SYSTEMS

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The advanced solar dynamic system (ASDS) program is aimed at developing the technology for highly efficient, lightweight space power systems. The approach is to evaluate Stirling, Brayton and liquid metal Rankine power conversion systems (PCS) over the temperature range of 1025 - 1400K, identify and prioritize the critical technologies and develop these technologies.

Microgravity fluid management technology is required in several areas of this program, namely, thermal energy storage (TES), heat pipe applications and liquid metal, two phase flow Rankine systems.

Utilization of the heat of fusion of phase change materials offers potential for smaller, lighter TES systems. The candidate TES materials exhibit large volume change with the phase change. A major uncertainty of TES materials operating in microgravity is void location, its impact on heat transfer and stresses and the repeatability of the storage/retrieval cycle.

The heat pipe is an energy dense heat transfer device. A high temperature application may transfer heat from the solar receiver to the PCS working fluid and/or TES. A low temperature application may transfer waste heat from the PCS to the radiator. The uncertainties of heat pipes in microgravity are startup rates, transient operation, depriming, burnout and restart capability.

The liquid metal Rankine PCS requires management of the boiling/condensing process typical of two phase flow systems.

The objective of the ASDS program is to develop the technologies for power systems operating in the temperature range of 1025 - 1400 K and power levels of 3-300 KWe.

A current contract with Rocketdyne will identify missions, select power levels and compare the performance and specific weight of Stirling, Brayton, and liquid metal Rankine solar dynamic power systems. This will be compared with the efficiency and specific weight of Photo-Voltaic systems.

Concentrator technology is evaluating lightweight, highly accurate reflecting surfaces and refracting surfaces such as a domed Fresnel lens. Two contracts are planned for FY 87 to study advanced concentrator technology. The use of micro-sheet glass for a second surface concentrator with silver or aluminum and epoxied to an appropriate substrate is being evaluated as a separate effort. The domed Fresnel lens concentrator is currently being studied by Entech, Inc.

Advanced heat receiver designs are currently being developed on parallel contracts with the AiResearch Manufacturing Company and Sanders and Associates. An in-house materials effort is aimed at identifying TES materials which will span the temperatures of interest and conducting compatibility tests of TES and containment materials.

ASDS PROGRAM OVERVIEW

- SYSTEMS STUDIES
- CONCENTRATOR TECHNOLOGY
- HEAT RECEIVER TECHNOLOGY
- CONCENTRATOR/RECEIVER SUBSYSTEM TEST
- PCS TECHNOLOGY
- HEAT PIPE RADIATOR TECHNOLOGY
- CRITICAL TECHNOLOGY VERIFICATION IN LEO
- SYSTEM TESTS

FIGURE 1

The concentrator and heat receiver technology efforts will lead to component tests for complete characterization. Component testing will lead to a concentrator/heat receiver subsystem test.

The current systems study indicates that the liquid metal Rankine PCS resulted in a substantially higher specific mass than either the Stirling or Brayton PCS. The Stirling free piston engine is being developed at the 25 KWe level on the SP-100 program. Advanced Brayton technology will be developed via foil bearing rig tests and hot turbine tests using refractory or ceramic materials.

Heat pipe radiator technology will begin in FY 88 and be conducted at the sub-component level. Critical technology verification in LEO is in support of the TES sub-system and will be described in some detail later.

Component testing in each technology area and sub-system tests will lead to a full-up system test. The power level of the systems test will be determined from systems studies and available test facilities.

An ASDS application where microgravity fluid management technology is required is that of a solar receiver with integral TES. The mass of TES material can be reduced by utilizing a phase change material having a high heat of fusion and appropriate thermal properties. Many of the candidate salts such as LiF, NaF and MgF_2 exhibit large volume change with the phase change. The TES material is liquid when fully charged and solid with a substantial void when discharged. The location of the void, its impact on heat transfer and temperature distribution, container stresses and repeatability of the charge/discharge cycle are uncertain in microgravity.

The capability to predict the thermal performance and behavior of TES materials in microgravity and container stress levels is a critical technology for ASPS.

SOLAR RECEIVER WITH INTEGRAL TES

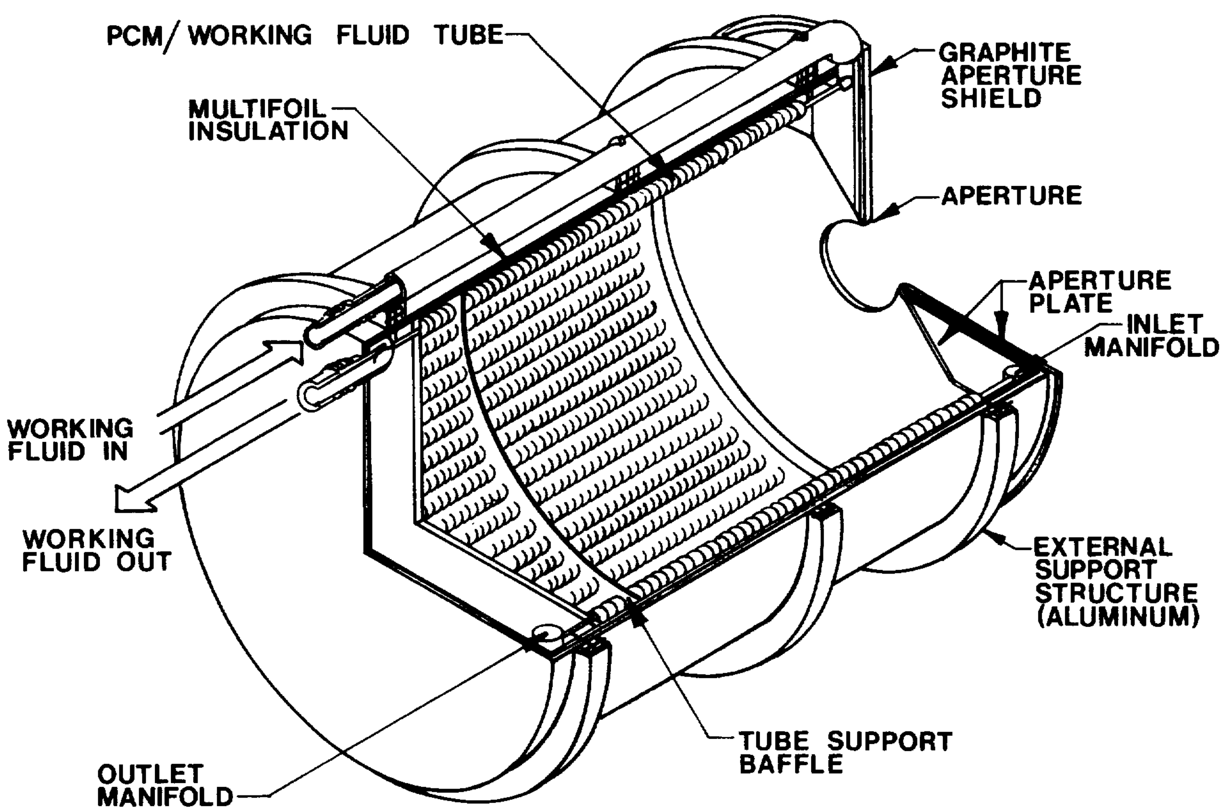


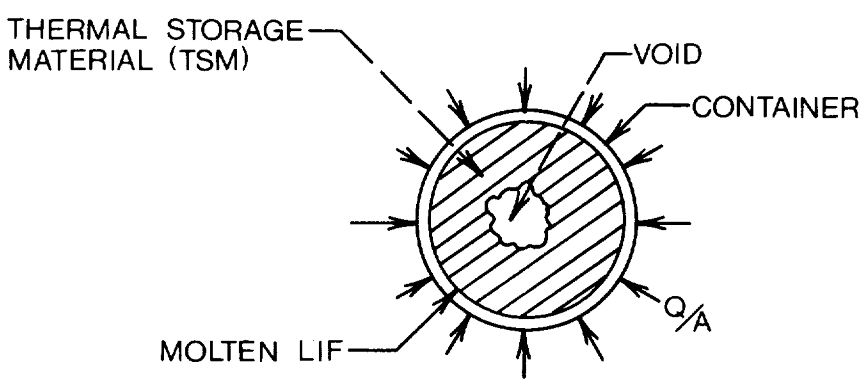
Figure 2

The stresses (thermal & mechanical), heat transfer, temperatures and void location in microgravity are dependent on configuration and the directions of heat storage and heat removal.

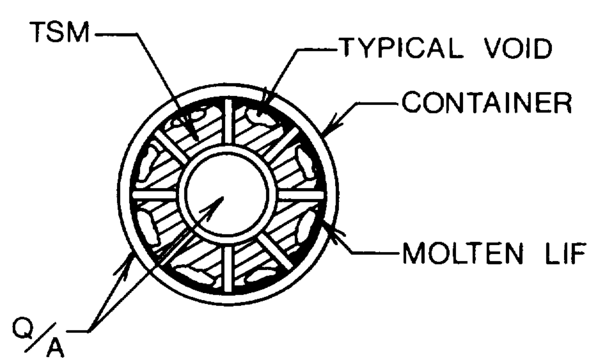
A cylindrical configuration with uniform heat addition and removal at the outer diameter is shown in Figure 3a. At the end of the discharge cycle (frozen), the void may be centrally located. On beginning the charge cycle (melting), the liquid TES expands and exerts a pressure on the TES material and containment shell. The magnitude of the stress in the containment wall depends on the relative strengths of the TES and container materials. Plastic deformation of the container could lead to a ratcheting condition and eventual failure of the container.

An annular configuration with external heat addition and internal heat removal is shown in Figure 3b. Fins are included to aid the heat transfer. At the end of the discharge cycle, the void may be located near the outer diameter of the container. Researchers anticipate that, on beginning the charge cycle, the expanding liquid will experience early communication with the void and reduced mechanical stresses.

TES CONFIGURATIONS



(a.) UNIFORM HEAT ADDITION AND REMOVAL

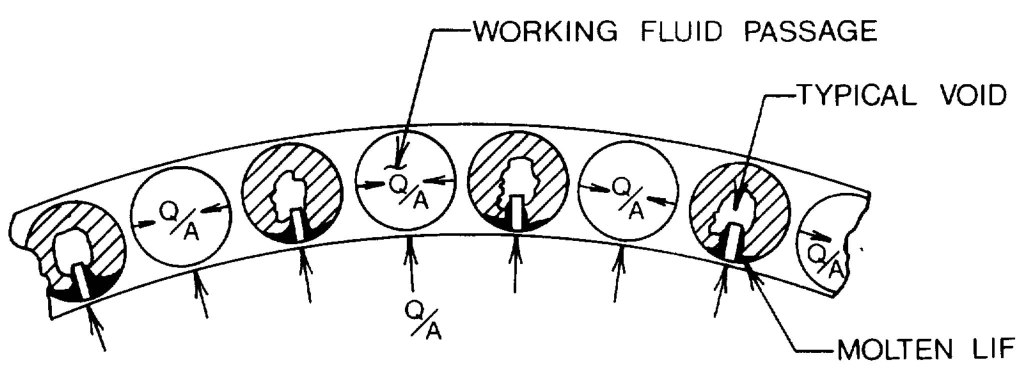


(b.) EXTERNAL HEAT ADDITION, INTERNAL HEAT REMOVAL

Figure 3

An alternate configuration shown in Figure 3c has internal heat addition and circumferential heat removal to and from the TES material. The void in the discharged TES material may be centrally located. Use of a thermal finger could provide early communication between the liquid and the void. This same concept could be applied to the cylindrical configuration.

TES CONFIGURATION



(c.) INTERNAL HEAT ADDITION, CIRCUMFERENTIAL HEAT REMOVAL

Figure 3 Continued.

The capability to design and operate TES subsystems in microgravity is a critical technology for ASPS. Verification of this technology in microgravity is necessary. A program has been planned which will develop and verify this technology in LEO.

An initial effort is the development of a computer program for transient thermal and stress analysis of TES materials operating in microgravity, including location of the void. Two approaches are being considered: a completely rigorous solution and an approximate solution. The approach selected will be consistent with the schedule requirements of the program.

Technology verification will be established by four flight experiments spanning the temperature range of interest.

Flight tests will be preceded by the design phase and extensive ground testing of each experiment to establish its thermal performance and flight capability. Safety of the experiment will be emphasized.

TES CRITICAL TECHNOLOGY VERIFICATION IN LEO

- DEVELOP COMPUTER PROGRAM FOR TRANSIENT THERMAL AND STRESS ANALYSIS OF TES MATERIALS IN MICROGRAVITY
- GROUND TESTS - PERFORMANCE AND FLIGHT QUALIFICATION OF 2-4 PROTYPICAL TES SPECIMENS
- FLIGHT TESTS - 2 - 4 TES SPECIMENS USING "GAS" OR "HITCH-HIKER" AS CARRIER
- POST FLIGHT EVALUATION - COMPARISON WITH ANALYTICAL PREDICTIONS
- TECHNOLOGY VERIFICATION

FIGURE 4

The flight experiments will be flown on the shuttle using the "Get-Away-Special" or "Hitch-Hiker" with opening lid containers. Each TES experiment will be subjected to 10 melt/freeze cycles closely approximating orbit times of 60/34 minutes of sun/shade, with prototypical heating rates and configurations. Thermal instrumentation with data acquisition and storage will define the transient thermal operation of the TES experiments. Post test sectioning will establish the void location. Correlation of predicted thermal performance and void location with flight results will verify this technology.

The heat pipe is an energy dense heat transfer device which utilizes the heat of vaporization and condensation of a working fluid. Heat is transferred at near isothermal conditions in this device. There are both high and low temperature potential applications of the heat pipe in ASDS.

A high temperature application of the heat pipe may be to transfer heat from the heat receiver to the heater head of a Stirling engine. A similar application exists for the solar dynamic Brayton engine.

Heat pipes and capillary pumped loops have operated in microgravity. The location of the working fluid is easily controlled in the 1g environment so that initial startup in microgravity will find the evaporator section with ample working fluid. Even so, the following uncertainties in microgravity exist:

o Transient operation and analysis

o Fast startup; burnout

o Restart capability

o Depriming - Vibrations or Accelerations

POTENTIAL HEATER MODULE — HEAT PIPE ARRANGEMENT

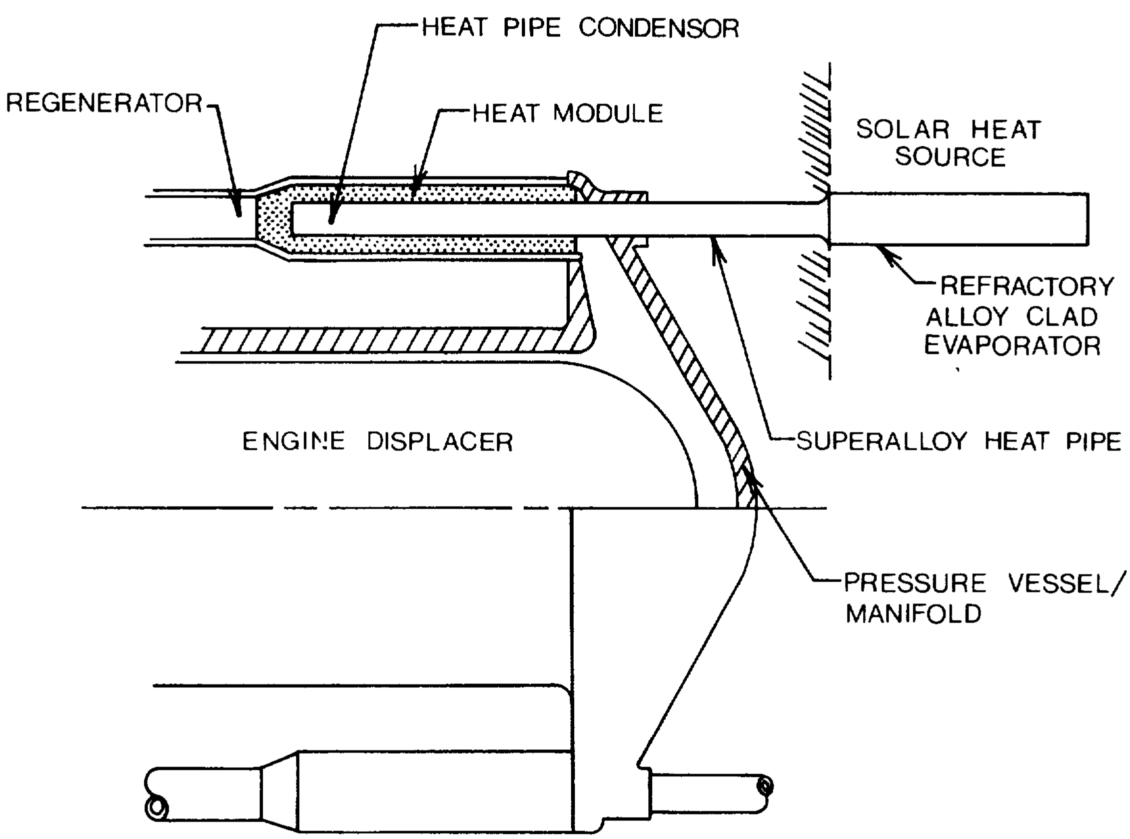


Figure 5

A low temperature application of the heat pipe may be to transfer waste heat from the power conversion system to and throughout the radiator. The concept shown below utilizes a pumped liquid loop (thermal bus) and heat pipes for transfer of heat to a number of finned panels.

The major concerns of the low temperature heat pipe are those discussed previously.

HEAT PIPE RADIATOR CONCEPT

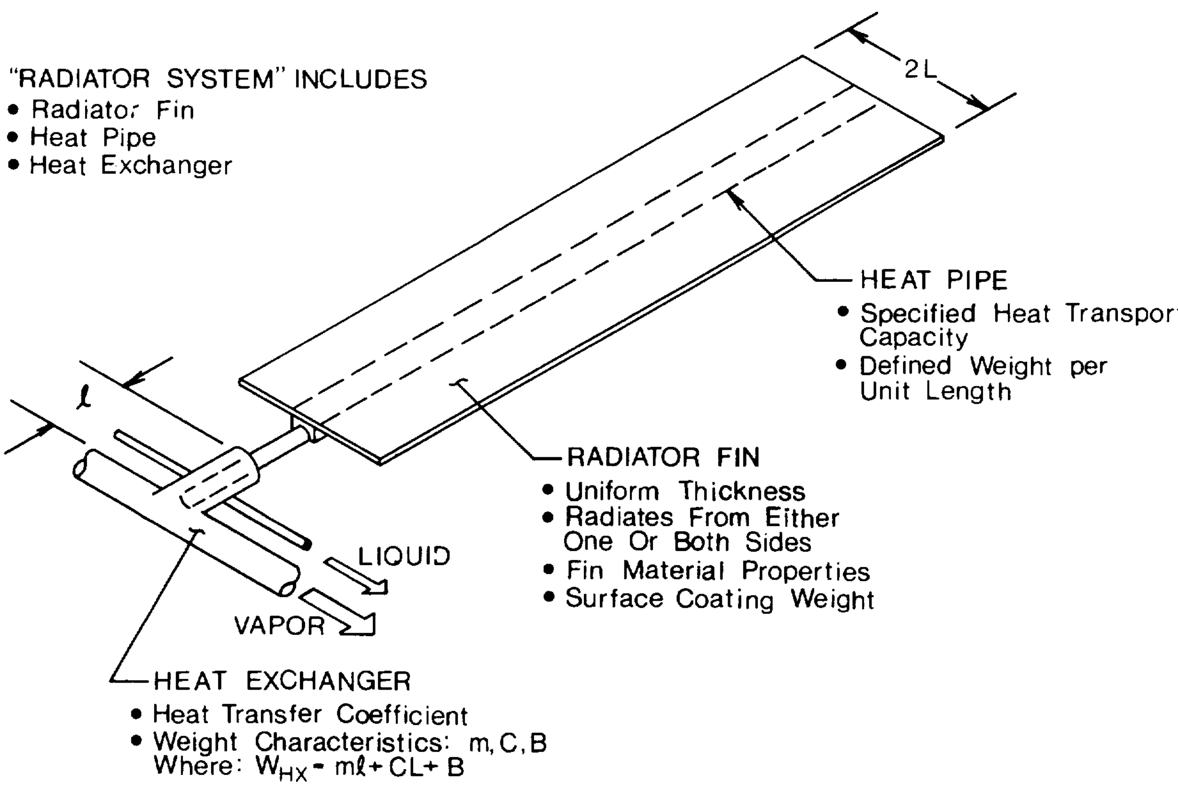


Figure 6

The heat pipe technology program of LeRC is still in a planning phase with certain program elements initiated. The procurement of an advanced radiator concepts study and the development of computer programs for steady state performance analysis have been initiated.

Sub-component development will include investigation of metal and ceramic composites as heat pipe structures, coating and surface treatments, wicking systems and capillary channels. Development of processing requirements will characterize contaminants, develop gettering systems and provide the procedures for cleaning, outgassing, filling and closing of heat pipes.

Life prediction will require the development of a life model and computer code. This model will be developed utilizing a data base of heat pipe experimental life data. In addition to the steady state performance analysis, transient analysis capability is required and will be developed.

Microgravity testing of heat pipes has not been included in the plan at this time. Further study of transient operation and restart in microgravity may lead to microgravity testing.

HEAT PIPE TECHNOLOGY PROGRAM

- ADVANCED RADIATOR CONCEPTS - CONTRACTOR
- SUB-COMPONENT DEVELOPMENT - IN-HOUSE
- PROCESSING REQUIREMENTS
- LIFE PREDICTION AND TESTING
- PERFORMANCE CODES - STEADY STATE AND TRANSIENT

FIGURE 7

The Rankine PCS was a third candidate for ASDS. However, the systems study at Rocketdyne has indicated that the Stirling and Brayton ASDS are more attractive than a liquid metal Rankine system on a specific weight basis. The Rankine PCS will therefore not be emphasized in the ASDS program.

The Rankine PCS is a viable candidate for the nuclear power system. The microgravity fluid management technology required for a boiling/condensing power system will be addressed by Dr. Antoniak.

TWO LOOP L.M. RANKINE SYSTEM

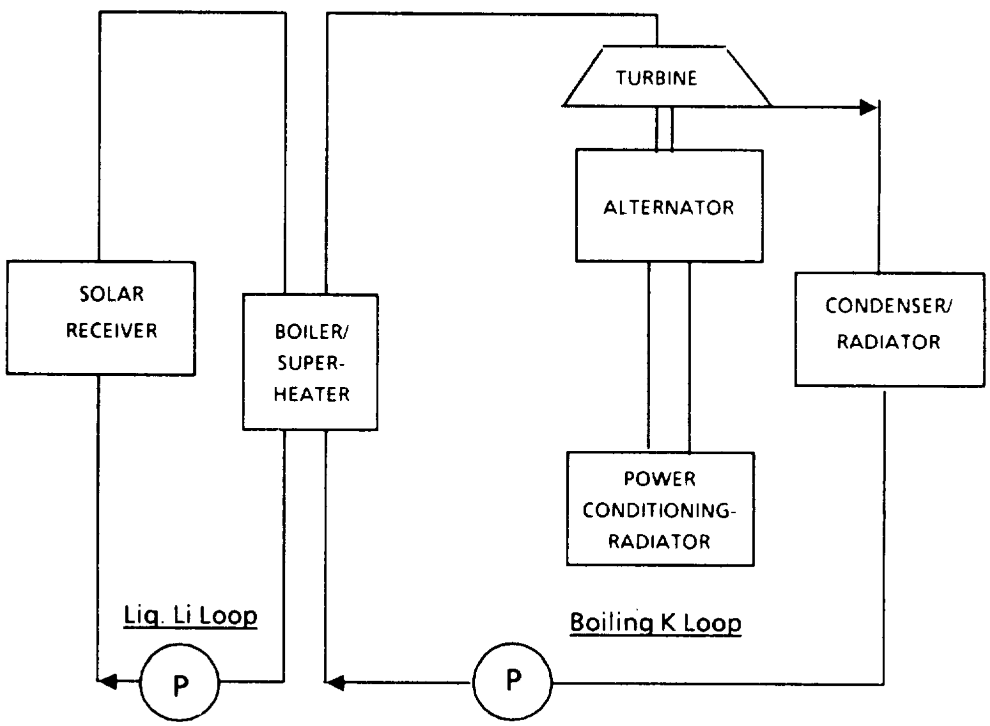


FIGURE 8

SUMMARY

The advanced solar dynamic power technology program considered three candidate power conversion systems: Stirling, Brayton and Liquid Metal Rankine. Each of these solardynamic power systems involves a microgravity fluid management technology.

A solar dynamic power system (SDPS) operating in a low earth orbit (LEO) requires an energy storage system if continuous power is to be provided over the entire sun/shade orbit. Thermal energy storage (TES) utilizing the heat of fusion of a salt such as LiF offers the potential for lightweight energy storage systems. However, the salts exhibit a large volume change (20 - 30%) on melting during heat addition. When the salts freeze during heat removal, they introduce a void. To design such systems for operation in space, one must be able to predict the shape and location of the void in microgravity on a transient basis and its impact on heat transfer and TES container stresses.

The heat pipe is an energy-dense heat transfer device, which requires no external pumping power to circulate the heat transfer fluid. Heat pipes may find application to SDPS in transferring heat from the receiver to the Sterling engine, in smoothing out temperature distributions within the heat receiver, or in transferring reject heat to the radiator. Low temperature heat pipes have operated in space on the shuttle. High temperature heat pipes must be properly designed and are expected to operate in the microgravity. The major uncertainties of heat pipes in microgravity are fast startup and potential burnout, restart capability, and depriming due to vibrations or accelerations. Thus, fluid management in microgravity is an important technology for heat pipe applications.

The liquid metal Rankine power system is a two-phase flow system where the liquid metal is boiled in the heat receiver and vapor is passed through a turbine where work is extracted; the vapor must then be cooled and condensed in a condenser or radiator. A net positive suction head is required at the pump circulating the liquid metal. Again, fluid management in microgravity is an important technology. Based on systems analysis, the liquid metal Rankine SDPS is not competitive with Stirling and Brayton. However, it is attractive for the nuclear power system so the microgravity technology may be required there.